Fuel Cells: Simple Solutions in a Complicated World

Rita A. Bajura
U.S. Department of Energy
Federal Energy Technology Center

Good morning. I'm pleased to speak to you at this joint review conference on fuel cell technology. I'd like to thank GRI for hosting this meeting. I'd also like to recognize the DOE staff at FETC and at the Office of Fossil Energy who worked with GRI and EPRI to plan this conference.

Several key issues are facing the energy industry:

- The first and perhaps the most important is climate change, the 30 percent increase in CO_2 concentrations in the atmosphere since pre-industrial times.

- Restructuring of the energy industry is another key issue. Who of the emerging players in the restructured industry is ultimately responsible for providing reliable energy supplies? Who provides public benefits? What do we do about the destitute who cannot pay market rates?

- Globalization is the final key issue. In the mid- to longer term, will nations really feel comfortable with out-of-country ownership of key portions of their energy industry?

As a society, I believe we are far from consensus on the appropriate long-term path forward for the energy industry. And that is a tough position to be in for an industry that typically has a 50- to 60-year lifetime for its capital assets.

The title of my talk is "Fuel Cells: Simple Solutions in a Complicated World." I believe fuel cells are a technological solution to some of the key issues facing the energy industry. Fuel cells bring technology to the rescue — just as we have used technology to solve so many other major issues facing society down through history. This title reflects my vision for the future of fuel cells. Fuel cells can help simplify this complicated picture in the energy world.

Why Fuel Cells Are a Major Thrust

Fuel cells are a major DOE thrust for several reasons:

- They could play a major role in a carbon-constrained future. Fuel cells could double the efficiency of fossil-based power generation, with a resultant slashing of CO_2 emissions. Operating on hydrogen, or with carbon sequestration, emissions from fuel cells would be zero.

- A huge manufacturing industry at stake. By 2010, fuel cells could account for as much as one-tenth of the $50-billion-per-year global market for power generation equipment. At stake are thousands of U.S. manufacturing jobs and millions of dollars in U.S. tax revenue.

- Foreign governments are teaming with their domestic manufacturers on technology development programs. Put simply: We're in a race! And I believe that continued Government support for cost-shared R&D on fuel cells is important to keep the U.S. in the race.

What FETC Is:

Most of you are familiar with my organization, the Federal Energy Technology Center — FETC for short. But for those of you who are not, we are a DOE field office located in Pittsburgh, Pennsylvania, and Morgantown, West Virginia. We report to the Office of Fossil Energy.

We are unique in that we are a Government-owned, Government-operated research and contract-management facility. Our mission is to solve national energy and environmental problems. Most of our R&D supports DOE's Office of Fossil Energy, but we support other parts of DOE and other Federal agencies as well.

We conduct more than 600 research, development, and demonstration (RD&D) activities in 49 states and 16 countries. Our FY 1999 budget is $717 million. This is augmented with significant cost-sharing from private sector participants in the RD&D programs.

FETC's Fuel Cell Program

Our fuel cell program has six major elements: molten carbonate fuel cells; solid oxide fuel cells; hybrid fuel-cell/gas-turbine systems; the Climate Change Program, which we execute for DOD; in-house research on PEM fuel cells; and 21st century fuel cells. In the following slides, I will briefly describe each of these program elements. The unifying parameter in all these elements is that they are fuel cells for stationary power applications.

The title on this slide says "FETC." But in truth, these programs are collaborative programs. They represent collaborations with other funding agencies: EPRI, GRI, DOD, the National Institute of Standards and Technology, EPA, the California Energy Commission, and our DOE sister organizations, the Office of Energy Efficiency and Renewable Energy (EE), and the Office of Nuclear Energy. They also represent collaborations with the performers of the R&D: our industrial partners and the national labs, non-profit labs, and universities in our program

FETC's Fuel Cell Budget

Fuel cells are a substantial part of our R&D portfolio. For the past several years, the fuel cell budget has been $40 to $50 million per year. Currently, we provide more funding for fuel cell research than any other organization in the U.S.

Specifically, in FY 1998, FETC's total fuel cell budget was $44.5 million; this year it's $51.9 million. While the fuel cell budget for FY 2000 is still being decided on by Congress, we expect that it will also be within this range. The recent Senate's mark for the Fossil Energy fuel cell piece — the top three lines on this slide — is $36.7 million. This was the DOE request to Congress. The House mark is $44.6 million. We anticipate that the final FY 2000 budget will be resolved in conference in the next several weeks.

Molten Carbonate Program

Molten carbonate is the first element of our fuel cell program. The goal is to develop and commercialize low-cost, packaged fuel cell power plants. We fund two separate molten carbonate fuel cell development teams:

- The first is the Energy Research Corporation, or ERC (soon to be renamed Fuel Cell Energy, Inc.). ERC is developing an externally manifolded, internally reforming molten carbonate fuel cell. They recently completed a 4,000-hour, 250-kilowatt tall stack test in Danbury, Connecticut. They are also conducting a grid-connected tall stack test in Danbury. On the manufacturing side, they have constructed a 5-megawatt-per-year molten carbonate fuel cell manufacturing plant at Torrington, Connecticut.

- The second molten carbonate fuel cell team (in alphabetical order) is M-C Power. They are developing an internally manifolded, externally reforming molten carbonate fuel cell. Recently, they completed two 75-kilowatt stack tests at the Miramar Naval Air Station in California. On the manufacturing side, they have constructed a 4-megawatt-per-year molten carbonate fuel cell manufacturing plant near here at Burr Ridge, Illinois.

The molten carbonate program is making excellent progress. It is working to resolve the remaining technology and systems issues: cost, thermal cycling, cathode corrosion, footprint, packaging and integration, and networking, The end goal of the program is a packaged, commercial product — not just a stack. The current contracts will culminate in multiple demonstrations of 300- to 1,000-kilowatt power plants. Cost targets are $1,000 to $1,500 per kilowatt by 2000.

Solid Oxide Program

We currently fund one major solid oxide fuel cell developer: Siemens Westinghouse. They are the acknowledged world leader in tubular solid oxide fuel cell technology. They are also the closest to commercializing a solid state fuel cell.

Siemens Westinghouse has also been making excellent progress! They tested stacks with multiple tubes for almost 70,000 hours with degradation of less than 0.1 percent per 1,000 hours. They have manufactured and tested several self-contained generators — up to 100-kilowatt size.

A 100-kilowatt generator test is underway in the Netherlands that has operated for more than 4,000 hours. They demonstrated operation at 15 atmospheres at Ontario-Hydro. Siemens Westinghouse has a nominal 4-megawatt-per-year manufacturing facility located near Pittsburgh, Pennsylvania.

Hybrid Fuel Cell/Turbine Systems

Hybrid systems are the third program element. These systems have the potential for very high efficiency; the fuel-to-electricity efficiency goal is 70 percent.

The first hybrid system will be demonstrated later this year. It is a 250-kilowatt system. Its efficiency goal is 60 percent. The members of the project team include Siemens Westinghouse, the University of California at Irvine, the California Energy Commission, and Edison Technology Solutions. This demonstration is a milestone in the fuel cell industry.

In a separate effort, five teams are developing conceptual designs and feasibility studies of hybrid systems. The goals are a minimum 70 percent efficiency and a cost of electricity 10 to 20 percent below today's conventional plants. The program targets systems smaller than 20 megawatts with the potential for commercialization by 2010. The teams are listed on the slide. Team members include Siemens Westinghouse, Allison, Solar Turbines, M-C Power, ERC, SOFCo, and the Northern Research and Engineering Corporation. DOE's Offices of FE and EE co-fund and co-manage the hybrid program. Nominally, FE and EE split responsibility for the hybrid program. EE is responsible for the microturbine; FE is responsible for the fuel cell and balance of plant integration.

Hybrid systems are an enabling technology for Vision 21 systems — more about his later.

Climate Change Program

The Climate Change Program is the fourth element of our program. It is funded by DOD's Construction Engineering Research Laboratory. FETC has executed the program for DOD in FY 1998 and FY 1999.

The goal of the Climate Change Program is to overcome the market entry hurdle of new technologies. The program offers fuel cell purchasers a $1,000-per-kilowatt rebate to offset the purchase price of a fuel cell demonstration. This rebate results in a large number of demonstrations, which builds up a manufacturing infrastructure, reducing fuel cell costs. This accelerates commercialization and lets society accrue the benefits of fuel cells earlier. In this case, the benefit is a reduction in greenhouse gas emissions.

Prior to FY 1998, the Climate Change Program only funded phosphoric acid fuel cells. In FY 1998, other fuel cell types were funded. The units funded to date include 141 200-kilowatt phosphoric acid fuel cell units; 106 PEM fuel cells (90 7-kilowatt units and 16 3-kilowatt units); and one 300-kilowatt solid oxide fuel cell unit.

For FY 2000, $5 million has been included in the House budget to continue this very successful program.

PEM Research at FETC

The fifth element of our program is PEM testing. This year, FETC began testing fuel cells in-house. Our facilities include a 5-kilowatt capacity test stand which can test multiple fuel cell types, and a 300-watt PEM fuel cell which can use hydrogen, natural gas, or methanol as the fuel source. The Institute of Gas Technology provided us the PEM fuel cell through a Cooperative Research and Development Agreement (CRADA).

Future of Fuel Cell Markets

Before I talk about the last element in our program, the 21st century fuel cell, I want to step back for a minute and discuss the future of fuel cell markets.

In the near-term, fuel cells are targeting four primary markets:

- The premium power market — computer centers, hospitals, and other facilities that must have a reliable supply of high-quality electricity and are willing to pay a premium price for it.

- Applications that can use opportunity fuels — sites that have waste methane gas such as landfills and breweries. Fuel cells can frequently compete in these applications because the fuel cost is near zero or there may even be a revenue stream for disposing of it.

- The green market — sites and facilities such as "green buildings" that want to demonstrate their commitment to the environment by acquiring a fuel cell.

- The grid-challenged market — such as end-of-line applications or sites where grid support is needed.

All of these market opportunities have locations that can support fuel cell capital costs of $3,000 to $4,000 per kilowatt. There will be further penetration into this market when fuel cells reach the target capital cost in our current program, which is $1,000 to $1,500 per kilowatt by 2003.

These four niche markets constitute a sizable market, but it is small in comparison to the bulk industrial, commercial, and residential market. The competition in these bulk markets is from reciprocating engines, microturbines, and grid connections. All are daunting competitors. The distributed power options — reciprocating engines and microturbines — are low cost and modular. Emissions are relatively low; efficiencies are not bad.

The fuel cell products emerging from our current program will begin to compete in this bulk market at the program's target cost of $1,000 to $1,500 per kilowatt. But for fuel cells to capture a significant share of the bulk power market, we believe fuel cells will need revolutionary improvements. Providing these revolutionary improvements is the goal of the 21st century fuel cell initiative.

Goals for 21st Century Fuel Cells

The goal of the 21st century fuel cell program is to develop advanced, solid state fuel cells with installed costs approaching $400 per kilowatt and efficiencies up to 80 percent. At these costs and efficiencies, fuel cells could penetrate the bulk market in a wide range of applications, including transportation.

Since we introduced the 21st century fuel cell program last fall, it has been enthusiastically embraced by the technical community. They see it as a tremendous opportunity to bring breakthrough technology to the table. The breakthroughs will come by integrating design, high-speed manufacturing, and materials selection from the start. An advanced, longer-term program like this cannot exist in a vacuum. There need to be spinoff improvements that can be applied to the nearer-term fuel cells in the program.

21st Century Initiatives

Listed here are three FETC initiatives to help us meet our goals for 21st century fuel cells.

The first is a Broad Agency Announcement (BAA) entitled "Multi-Layer Ceramic Fuel Cell Research." A BAA is a solicitation that stays open for some length of time and has periodic evaluation cycles. We issued the multi-layer ceramic BAA in June of this year, and it will stay open until June 2000. Its objective is to advance high-temperature, solid-state fuel cell design and manufacturing. The first of its three evaluation cycles closed at the end of July; we hope to announce awards by the end of September. If you are interested, this announcement is on FETC's website.

The second effort listed here is a strategic alliance we are developing with Pacific Northwest National Laboratory (PNNL). The purpose of this alliance is to work cooperatively to advance solid state fuel cell technology. FETC is funding the development of solid state fuel cells for stationary applications; PNNL is involved in fuel cell systems for transportation. It makes sense to have a collaborative program.

The third effort is a solicitation to address material and electrochemical issues in 21st century fuel cells. We just closed on a solicitation that was issued as a Program Research and Development Announcement (PRDA). We plan to announce the winners of this solicitation in the next few months.

Vision 21

Let me talk a bit about Vision 21.

Fossil fuels provide 85 percent of global and U.S. energy supply. Even under a climate change scenario, we will need to use fossil energy well into the future. But we need to use it smarter. The goal of Vision 21 is to wring every possible bit of useful energy out of carbon-based feedstocks to produce useful energy products. The program targets larger energy facilities, typically not distributed power sites. Vision 21 products can be electricity, fuels, or chemicals, with steam and heat as secondary products. The feedstocks can be natural gas, oil, coal, or biomass. Vision 21 also includes an option for carbon sequestration, thereby removing all environmental barriers from the use of fossil fuels.

We have set very aggressive efficiency goals for Vision 21 plants. For Vision 21 plants that produce electricity, both hybrid systems and 21st century fuel cells have a potential role in meeting these efficiency goals.

A few days ago, we issued a draft Vision 21 solicitation for proposals to make Vision 21 a reality. Its title is "Development of Technologies and Analytical Capabilities for Vision 21 Energy Plants." I

encourage you to take a look at this solicitation and provide us your comments. It on the FETC website.

Fuel Cell Program Future

This final slide shows the future of our fuel cell program. The figure on the left shows anticipated cost reduction as we move from today's phosphoric acid fuel cells, to molten carbonate fuel cells and solid oxide fuel cells in 2003, to hybrid systems in 2010, to 21st century fuel cells in 2015. The figure on the right shows electric efficiency improvement over the same period. These figures make it clear that the future of fuel cell development does not reside in marginal or incremental improvements. Our goal is to increase efficiencies by one-half in the next 15 years. Our goal is to slash installed costs to $400 per kilowatt.

Fuel cells are simple solutions in a complicated energy world. Technological and cost barriers remain to be overcome, but they will be overcome. The initiatives are in place. The people are right here in this room. Let us continue with our work to make this vision a reality.

Thank you.

Fuel Cells: Simple Solutions in a Complicated World

Presented by

Rita A. Bajura, Director

U.S. DOE Federal Energy Technology Center

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Why Fuel Cells Are a Major Thrust:

- Potential to Double Efficiency of Fossil-Based Power Generation
- Huge Manufacturing Industry at Stake
- Foreign Governments Teaming with Their Domestic Manufacturers

What FETC Is:

- An Industry-Focused Federal Organization Managing and Conducting Technology Development Programs
- Government Owned and Government Operated
- FY 1999 Budget of $717 Million

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FETC's Fuel Cell Program

- Molten Carbonate Program
- Solid Oxide Program
- Hybrid Fuel Cell/Turbine Systems
- Climate Change Program
- Proton Exchange Membrane Research
- 21st Century Fuel Cells

Fuel Cells for Stationary Applications

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FETC's Fuel Cell Budget ($ Million)

	FY 98	FY 99	FY 00
Molten Carbonate	23.0	25.7*	TBD
Solid Oxide	12.9	15.7	TBD
Other	4.3	8.0	TBD
Climate Change (DOD)	4.3	2.5	TBD

*Includes $5.2 from DOD CERL

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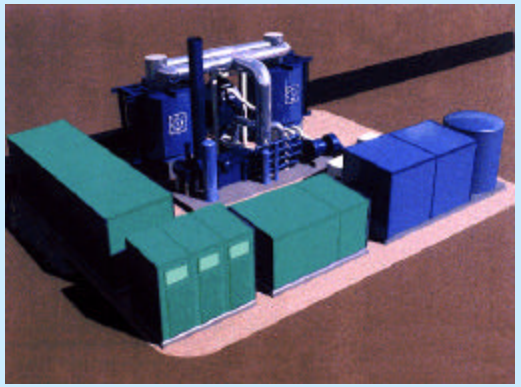
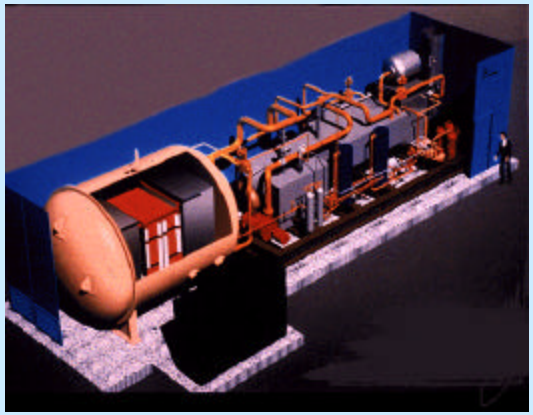
Molten Carbonate Program

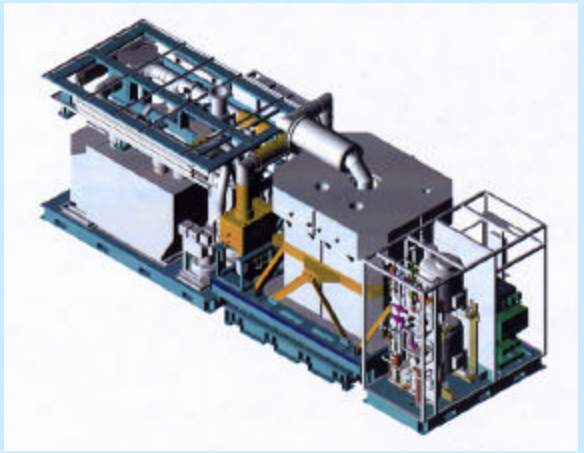
- Energy Research Corporation (ERC)
- M-C Power





Solid Oxide Program

- Siemens Westinghouse



Hybrid Fuel Cell/Turbine Systems

- **Goals**
  - 70% (LHV) Electric Efficiency
  - 20 MW or Less
  - Commercialization by 2010 (Off-the-Shelf)
- **Players**
  - Siemens Westinghouse/Allison
  - Siemens Westinghouse/Solar
  - M-C Power/Allison
  - ERC/Allison
  - SOFCo/Northern Research and Engineering Corporation
- **Co-Funded/Co-Managed by DOE/EE**
- **Enable Vision 21 Systems**

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FETC

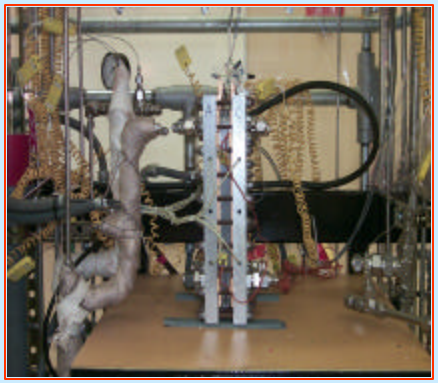
Climate Change Program

- **Funded by DOD/Construction Engineering Research Laboratory**
- **Implemented by FETC in FY 1998 and FY 1999**
- **Expanded to Other Fuel Cells in FY 1998**
- **To Date:**
  - 141 PAFC Units
  - 106 PEMFC Units
  - 1 SOFC Unit

PEM Research at FETC

- **Test Stand**
  - 5 kW Capacity
  - Multiple Fuel Cell Types

- **PEM Fuel Cell**
  - 300 watts, 3 volts
  - Hydrogen, Natural Gas, or Methanol Fuel Source



Future of Fuel Cell Markets

- Near-Term Limited Penetration Due to High Costs
- Long-Term Greater Penetration with Cost Reduction
- Competition is from Reciprocating Engines and Microturbines

Goals for 21st Century Fuel Cells

- Approaching $400/kW Installed Costs
- 80% (LHV) Electric Efficiency
- Applications in Distributed Power, Central Station Power and Transportation
- Broad Market Penetration

21st Century Initiatives

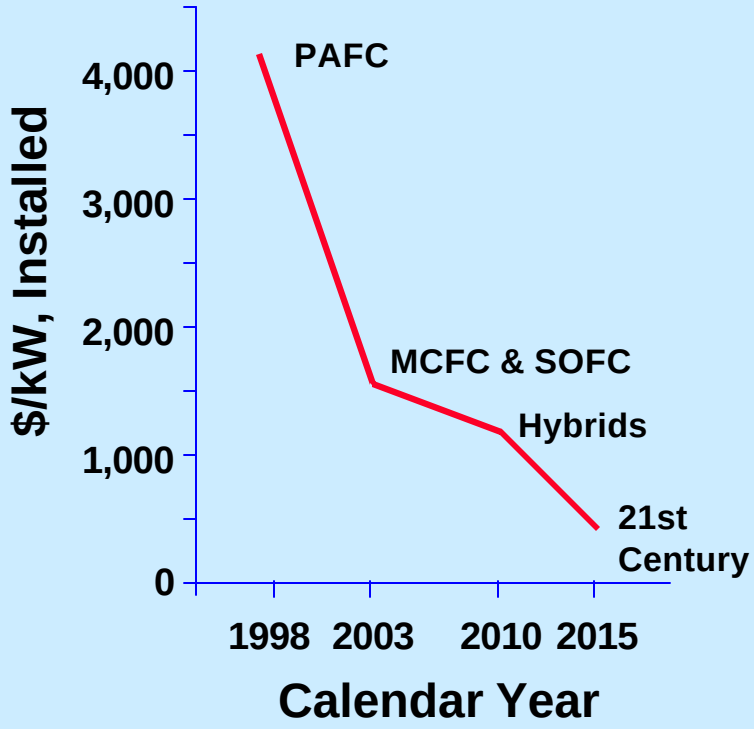
- Multi-Layer Ceramic Manufacturing
- Strategic Alliance with Pacific Northwest National Laboratory (PNNL)
- Advanced Research Program Research and Development Announcement

Vision 21

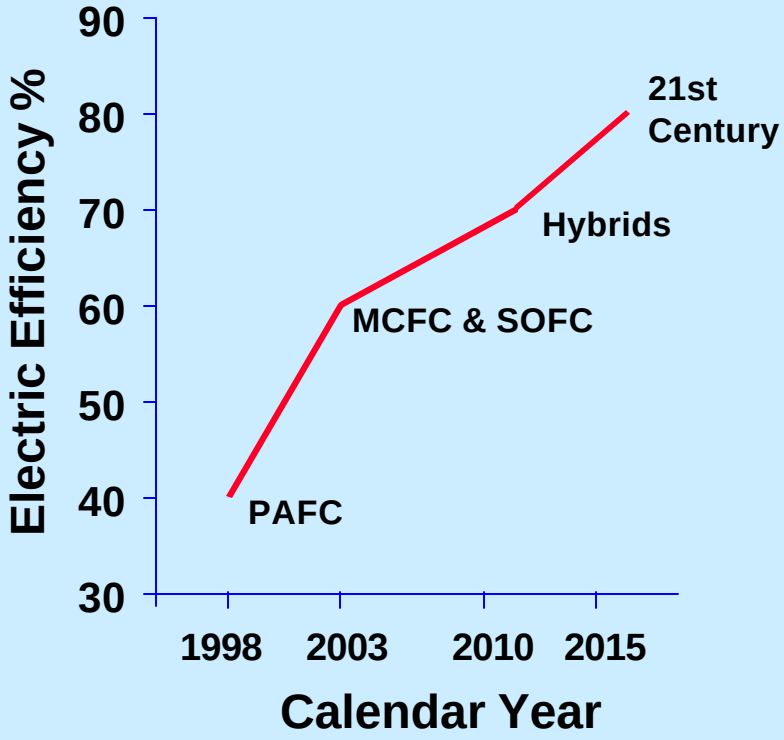
- Provides Technology for Generation of Low-Cost Electricity from Fossil Fuels in the 21st Century
- Removes Environmental Barriers to Fossil Fuel Use
- Continues U.S. Leadership in Clean Energy Technology

Fuel Cell Program Future

Cost Reduction



Efficiency Improvement



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